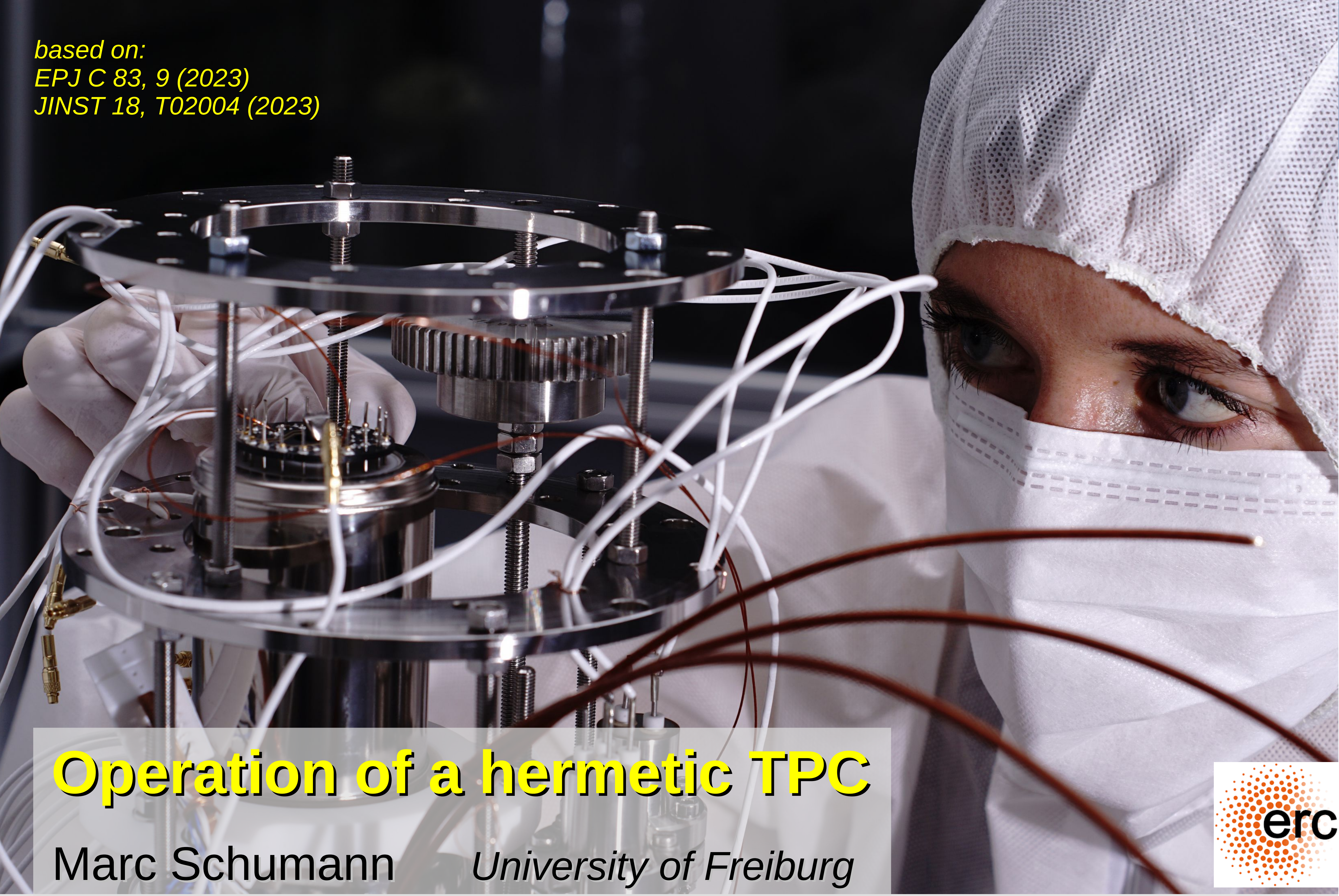


based on:
EPJ C 83, 9 (2023)
JINST 18, T02004 (2023)

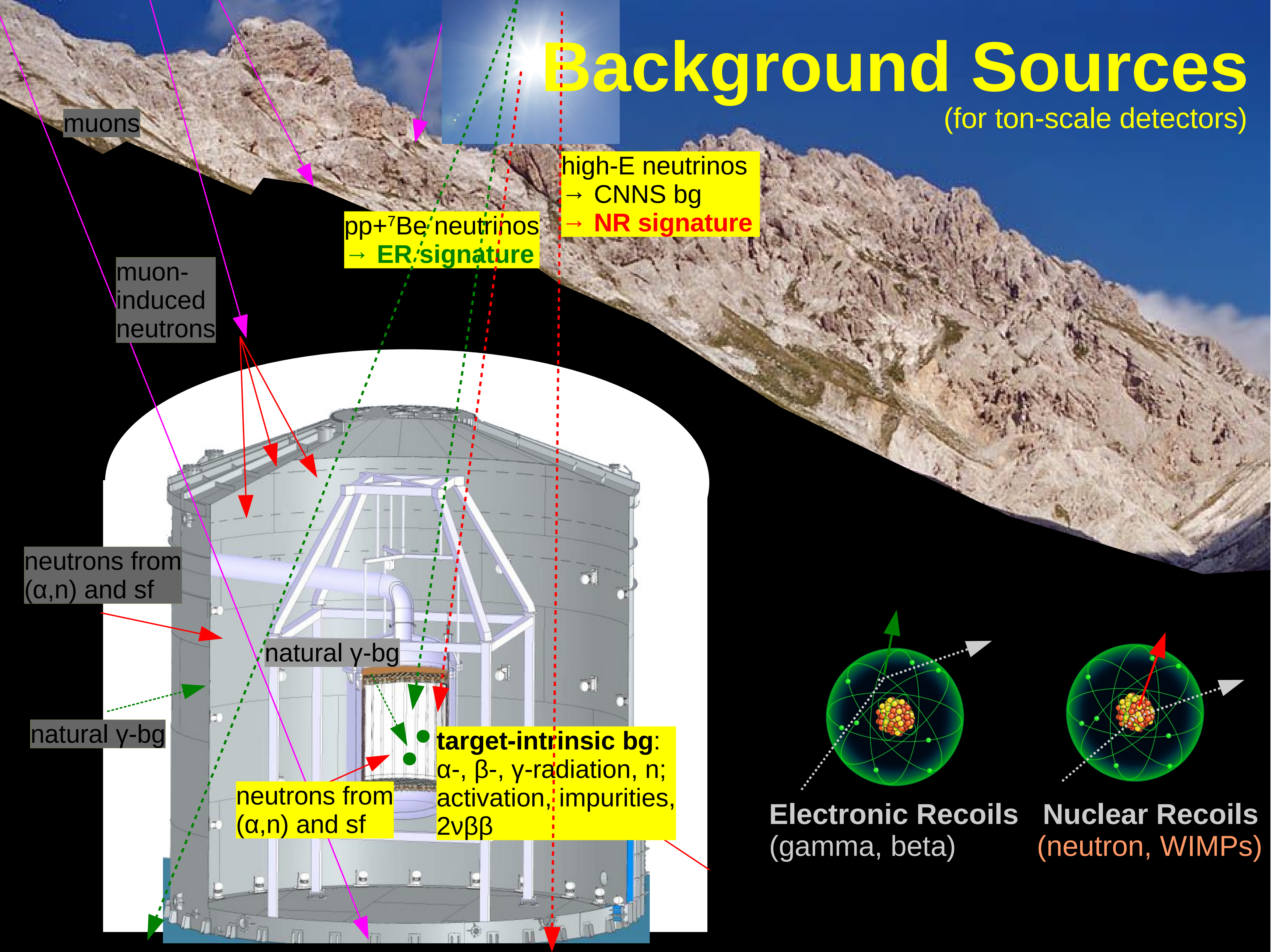
Operation of a hermetic TPC

Marc Schumann *University of Freiburg*

Nagoya Workshop on future liquid noble gas detectors, 14.02.2024

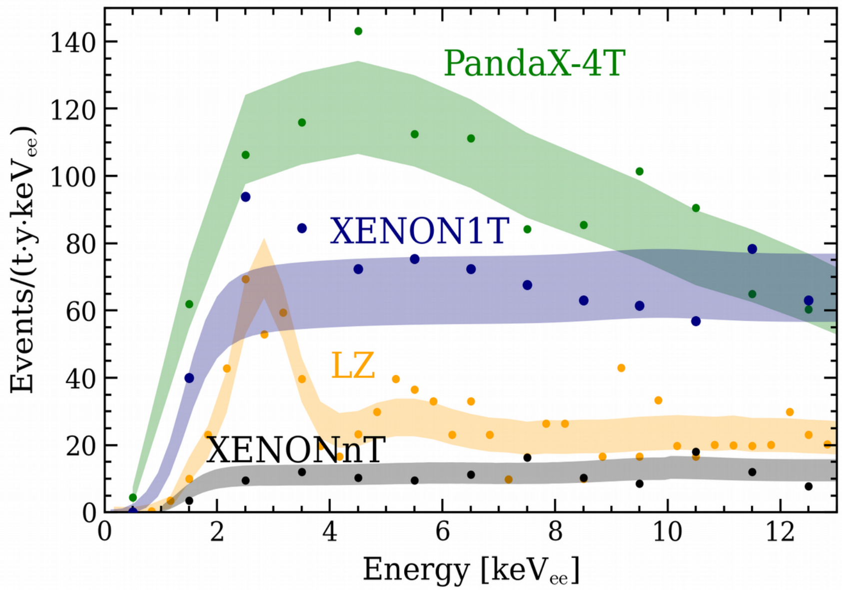
`www.app.uni-freiburg.de`

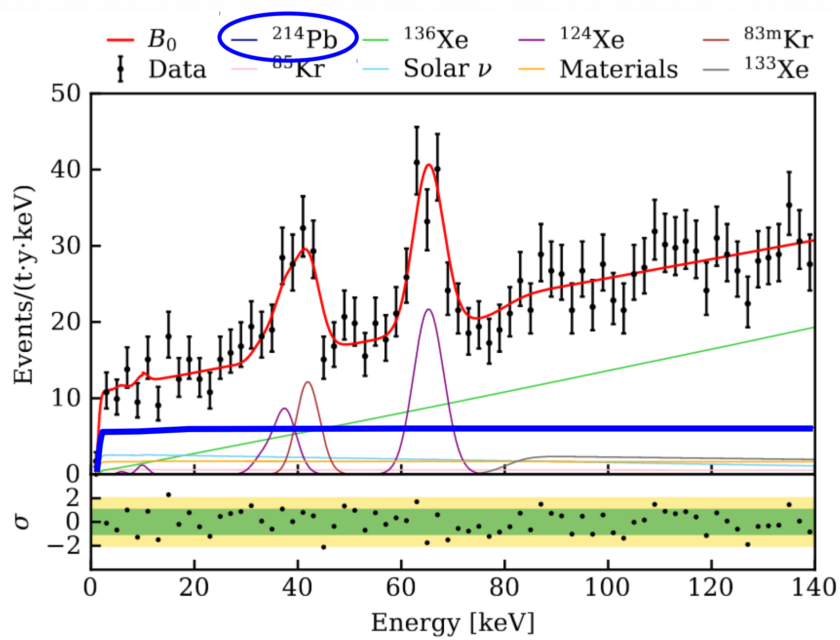
universität freiburg


Background Sources
(for ton-scale detectors)
muons
muon-induced neutrons
pp+⁷Be neutrinos
→ ER signature
high-E neutrinos
→ CNNS bg
→ NR signature
neutrons from (α,n) and sf
natural γ-bg
natural γ-bg
neutrons from (α,n) and sf
target-intrinsic bg:
α-, β-, γ-radiation, n;
activation, impurities,
2νββ
Electronic Recoils
(gamma, beta)
Nuclear Recoils
(neutron, WIMPs)

XENONnT: Lowest ER background

PRL 129, 161805 (2022), PRD 108, 012016 (2023)



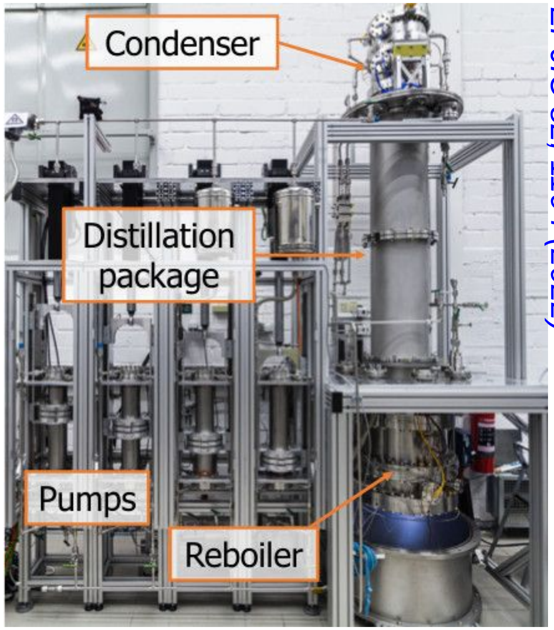


Rn dominates low-E ER background of current detectors

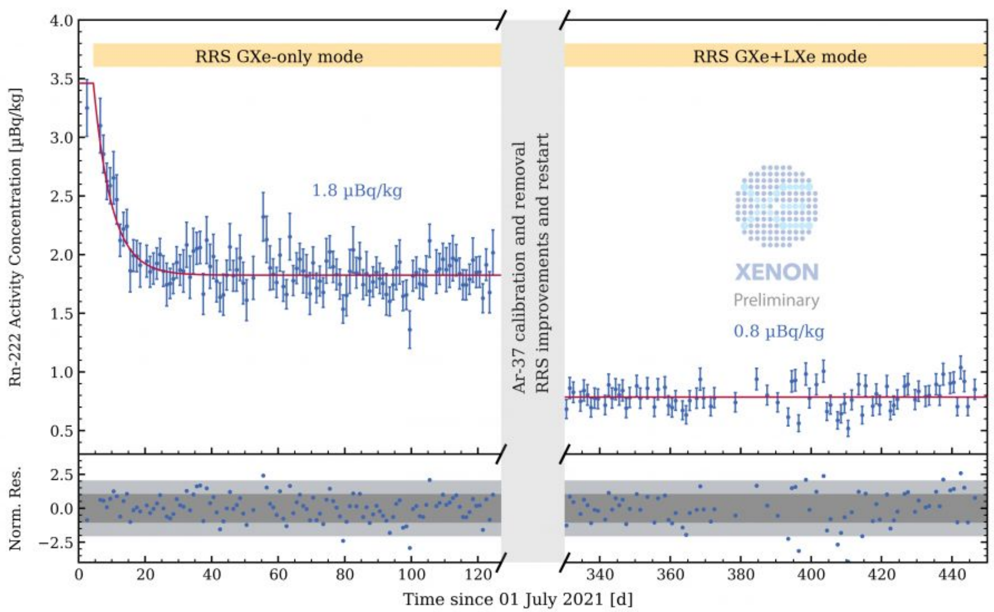
Active on-line Rn removal via cryogenic distillation

Initially demonstrated on XENON100

EPJ C 77, 358 (2017)



EPJ.C 82, 1104 (2022)



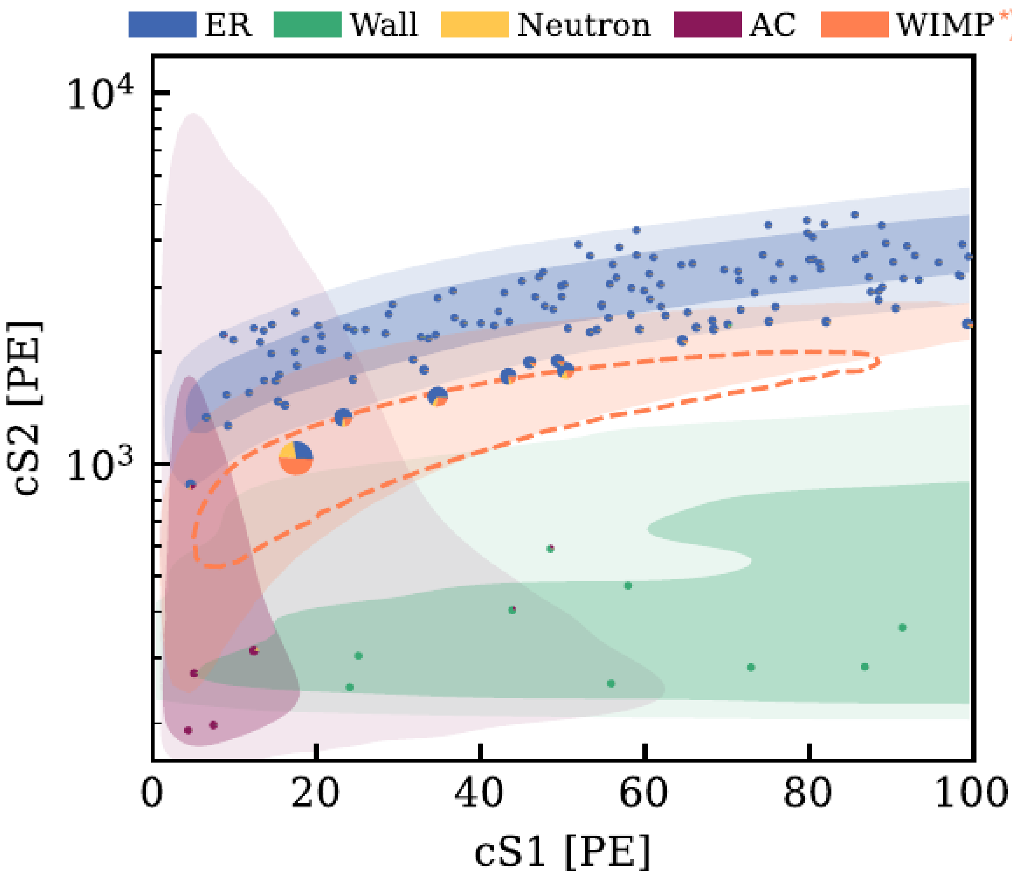
XENON WIMP Search

PRL 131, 041003 (2023)

	Expectation	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.81 ± 0.07
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.2	0.42 ± 0.10
CEvNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.011
AC	4.3 ± 0.2	4.32 ± 0.15	0.363 ± 0.013
Wall	14 ± 3	12^{+0}_{-4}	$0.34^{+0.01}_{-0.11}$
Total	154	152 ± 12	$1.95^{+0.12}_{-0.16}$
WIMP		2.4 *)	1.2 *)
Observed		152	3

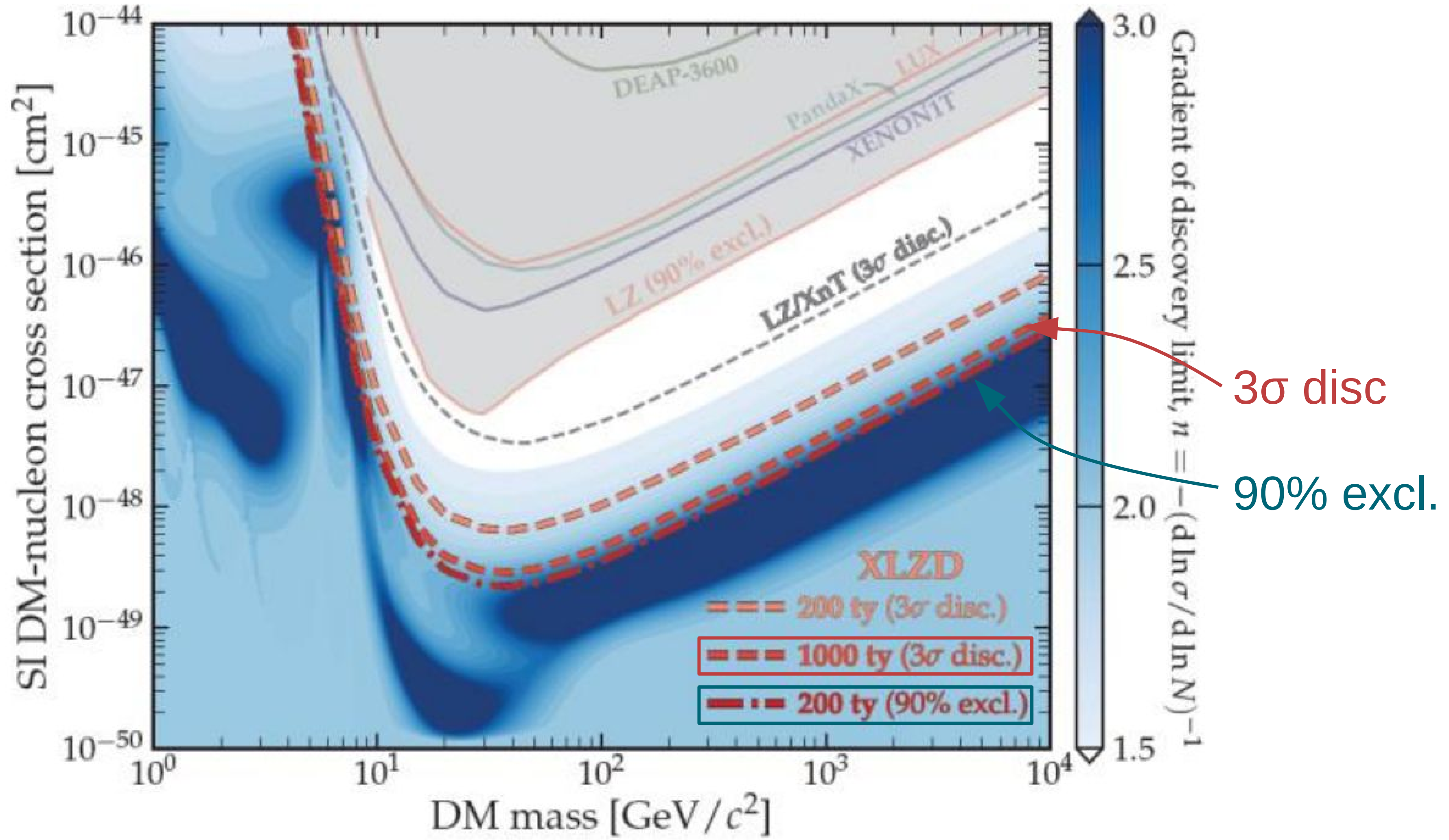
152 events in ROI, 16 in blinded region

Best fit indicates no significant excess



*) Assuming a 200 GeV WIMP and a best-fit σ = 2.5×10^{-47} cm²

Towards the neutrino floor



200 t×y: probe entire mass range ≥10 GeV at 90% CL

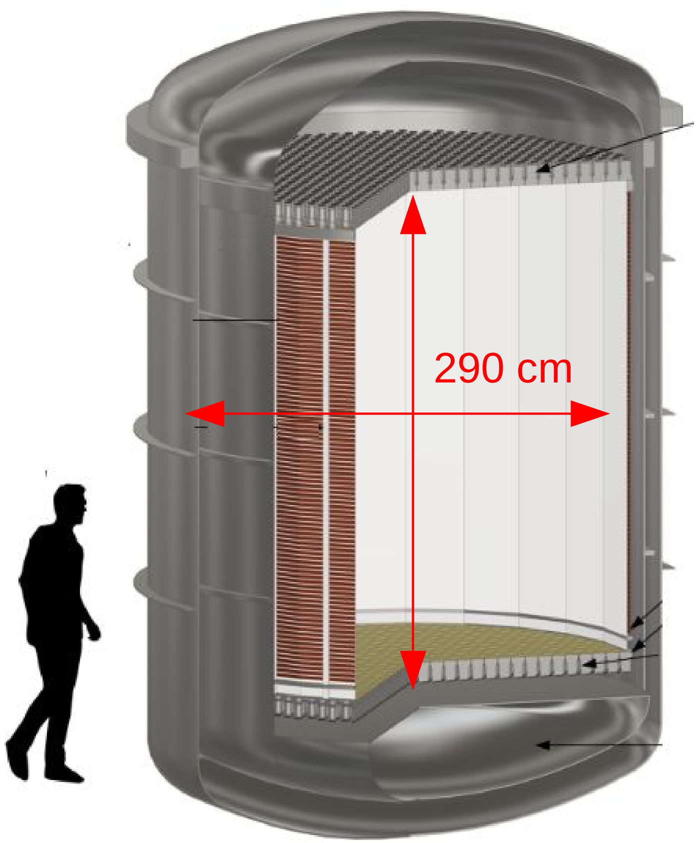
1000 t×y: probe entire mass range ≥10 GeV at 3σ evidence

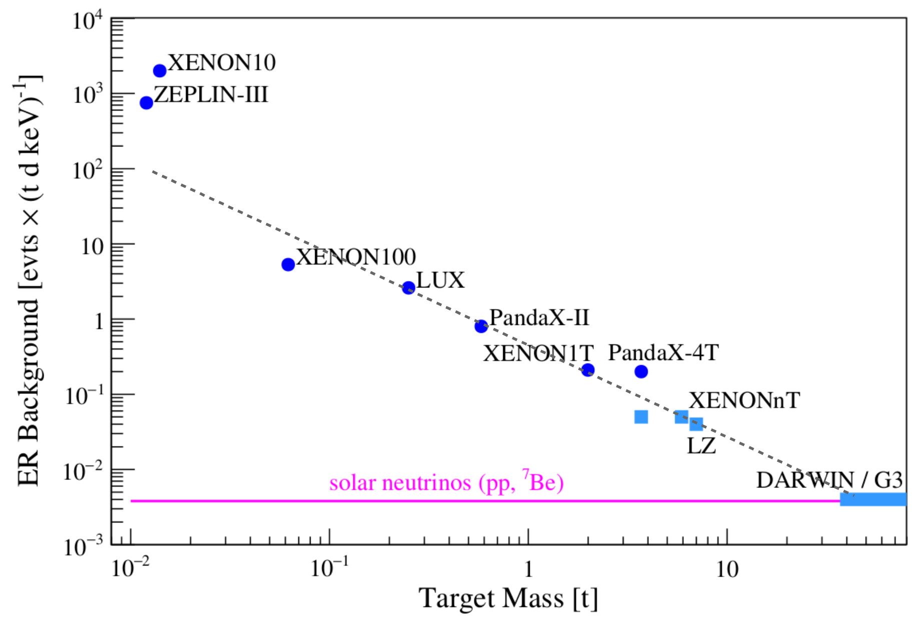
The ultimate LXe WIMP Detector

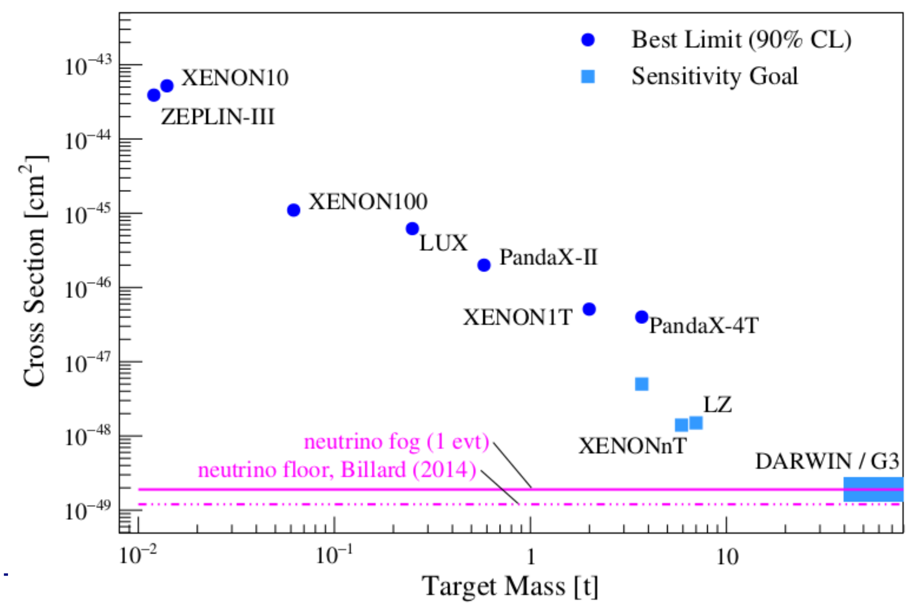
Background dominated by **irreducible neutrinos**

Baseline design
~73t total LXe mass
~60 t LXe TPC
~54 t fiducial mass

PRELIMINARY

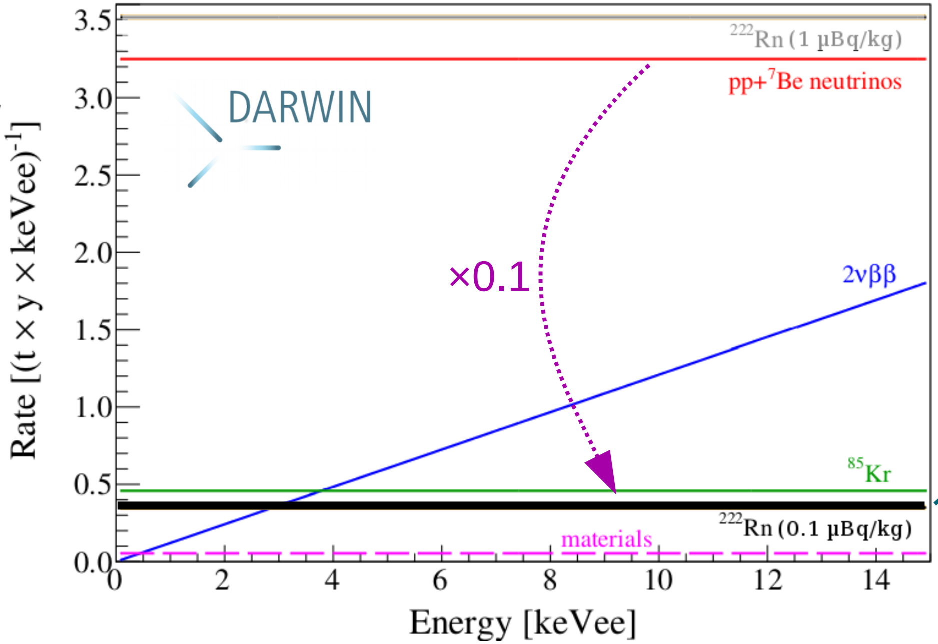






Radon Background

JCAP 10, 016 (2015)



Background goal:
ER background dominated by solar neutrinos

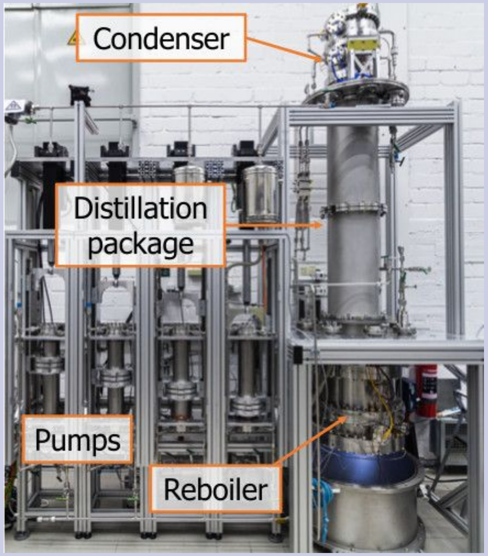
^{222}Rn emanated from all detector surfaces.
Need concentration
factor ~50 below XENON1T
factor ~8 below XENONnT

→ **main background challenge**

Strategy

– active Rn removal via cryogenic distillation
→ column developed for XENONnT is R&D for XLZD

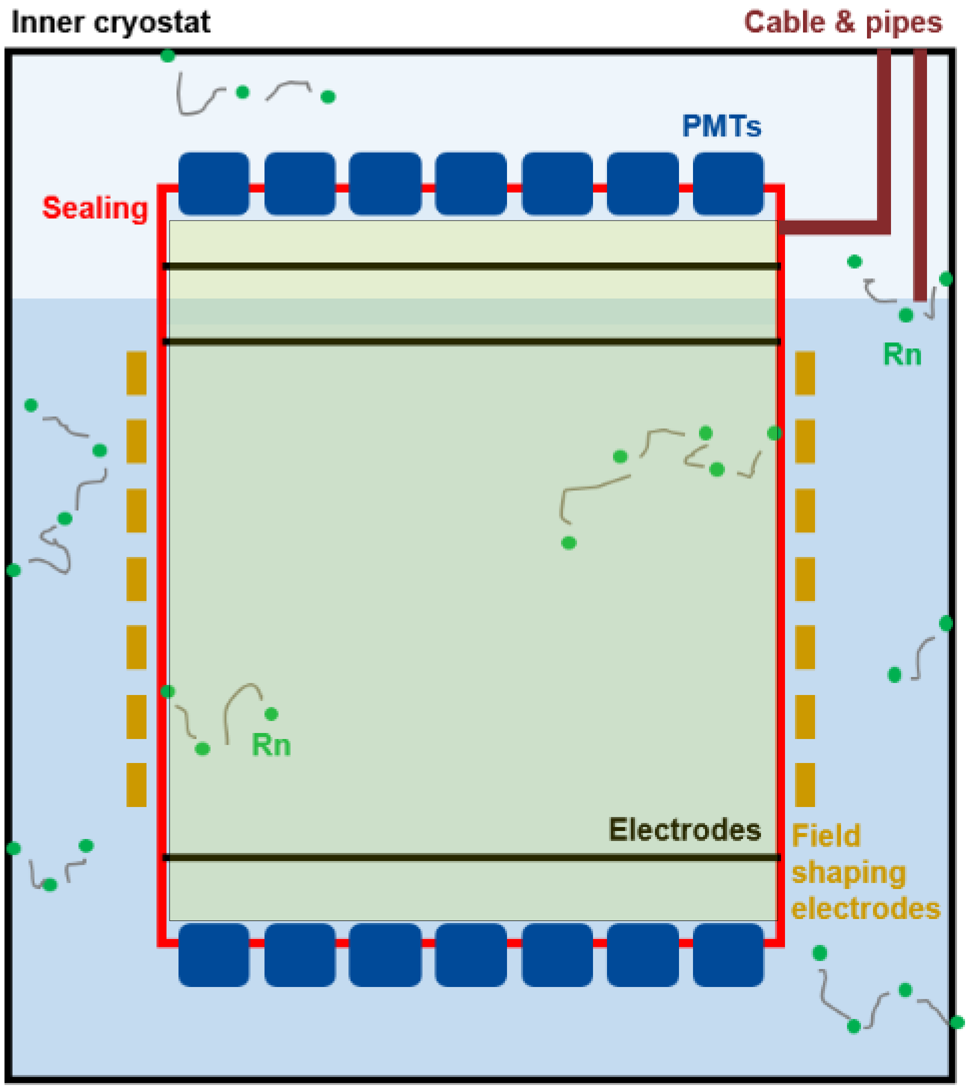
– avoid Rn emanation by
→ optimal material production
→ material selection
→ surface treatment
→ **optimized detector design**



Hermetic TPC: The Concept

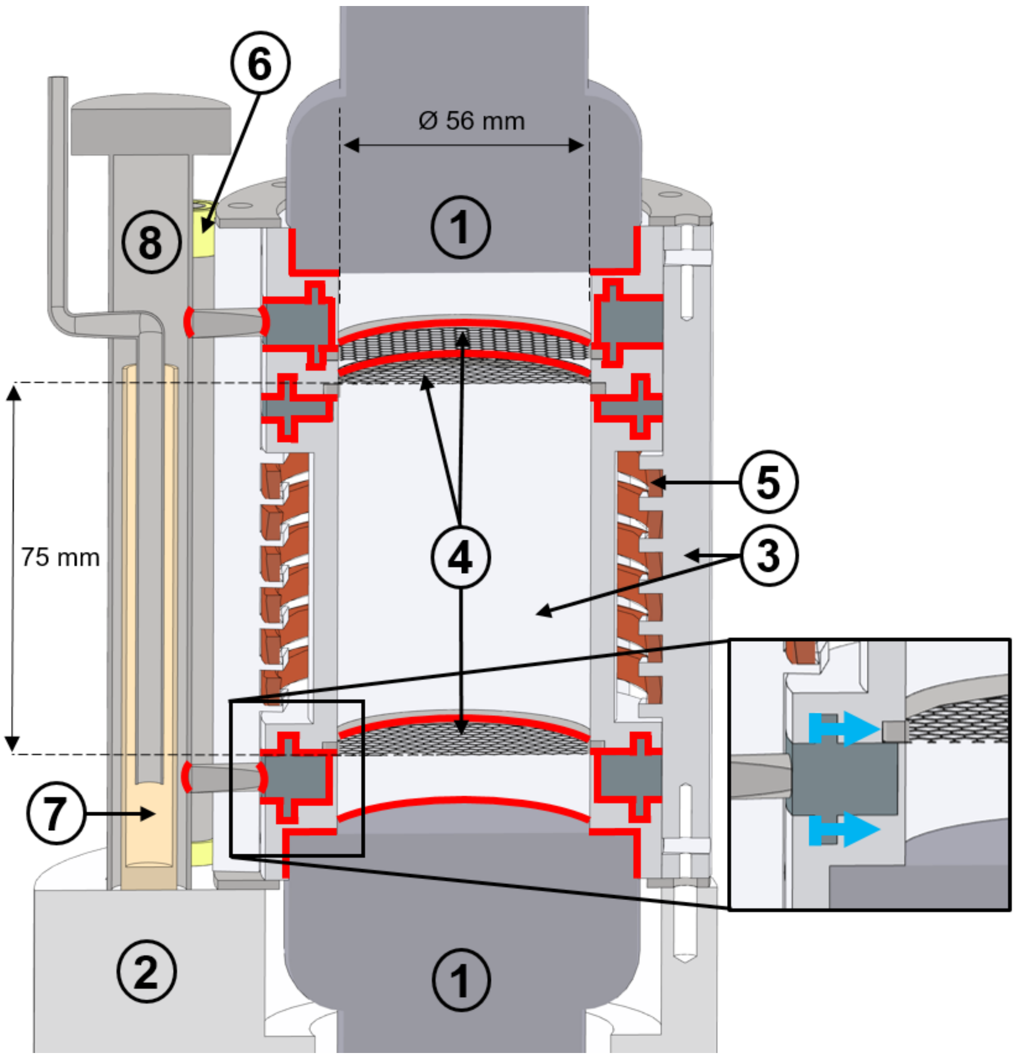
- Rn emanated from surfaces
- About 10x more surfaces outside of active TPC target
- In addition: all „dirty“ components in outer volume (cables, HV dividers)

- Reduce Rn by mechanically separating inner and outer volumes
- BUT: depart as little as possible from well-established, successful TPC designs



Our Design

- „Typical“ TPC
  – 3 mesh electrodes
  – PTFE reflector tube
  – PMTs in contact with target
- Sealing done via cryofitting
  (=exploit difference in
  linear expansion coefficients)
- LXe level controlled with weir



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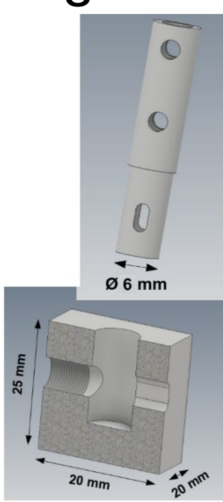
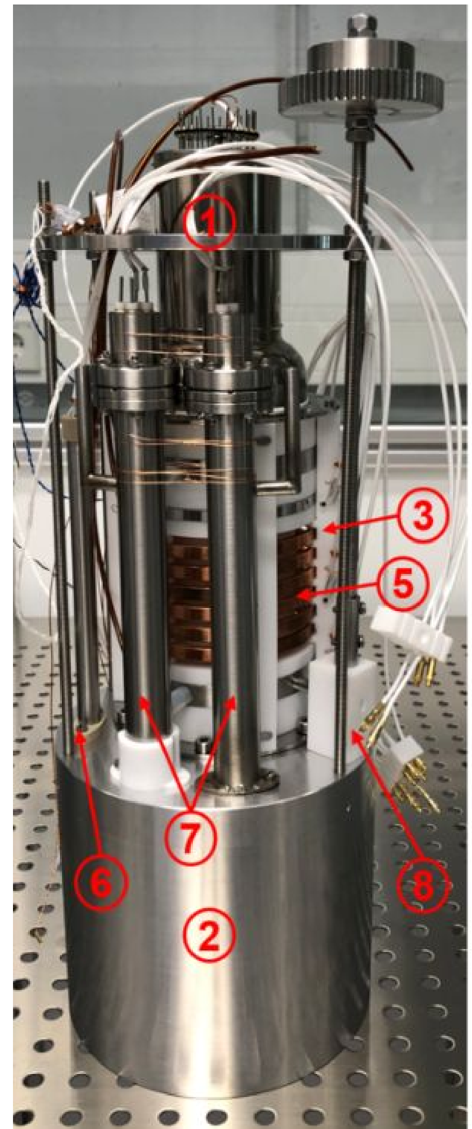
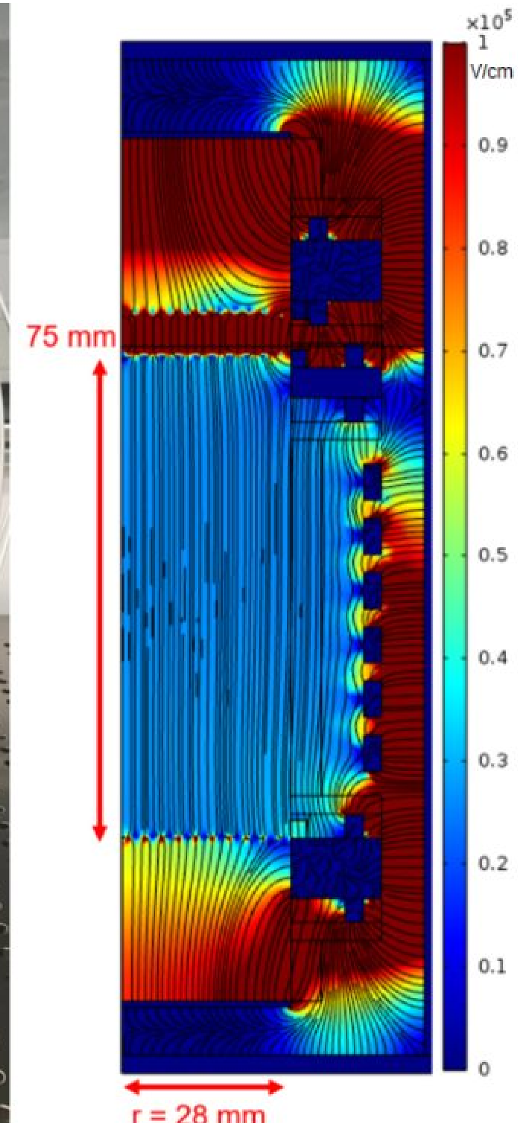
- Electric field homogeneity confirmed with COMSOL
- LXe level control with weir
- Valve connecting both volumes for filling and recuperation







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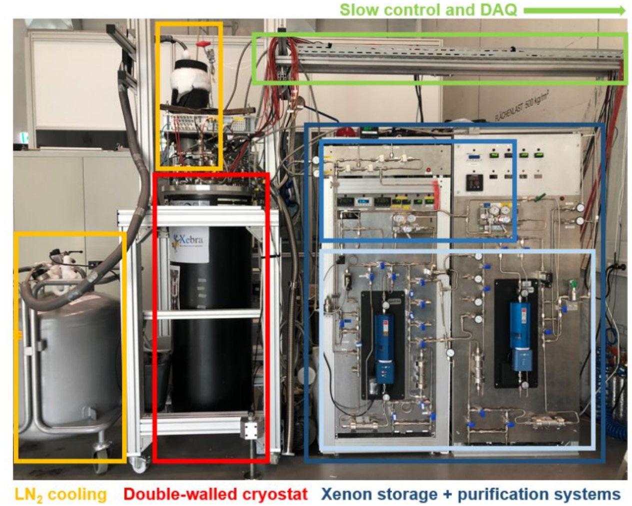
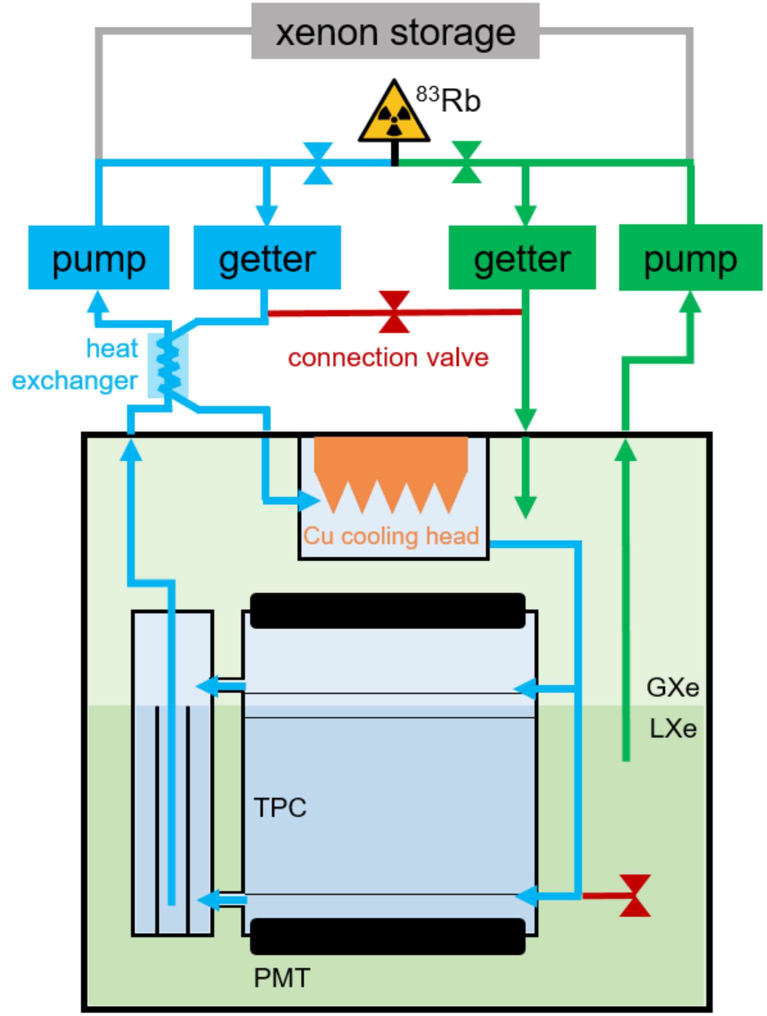
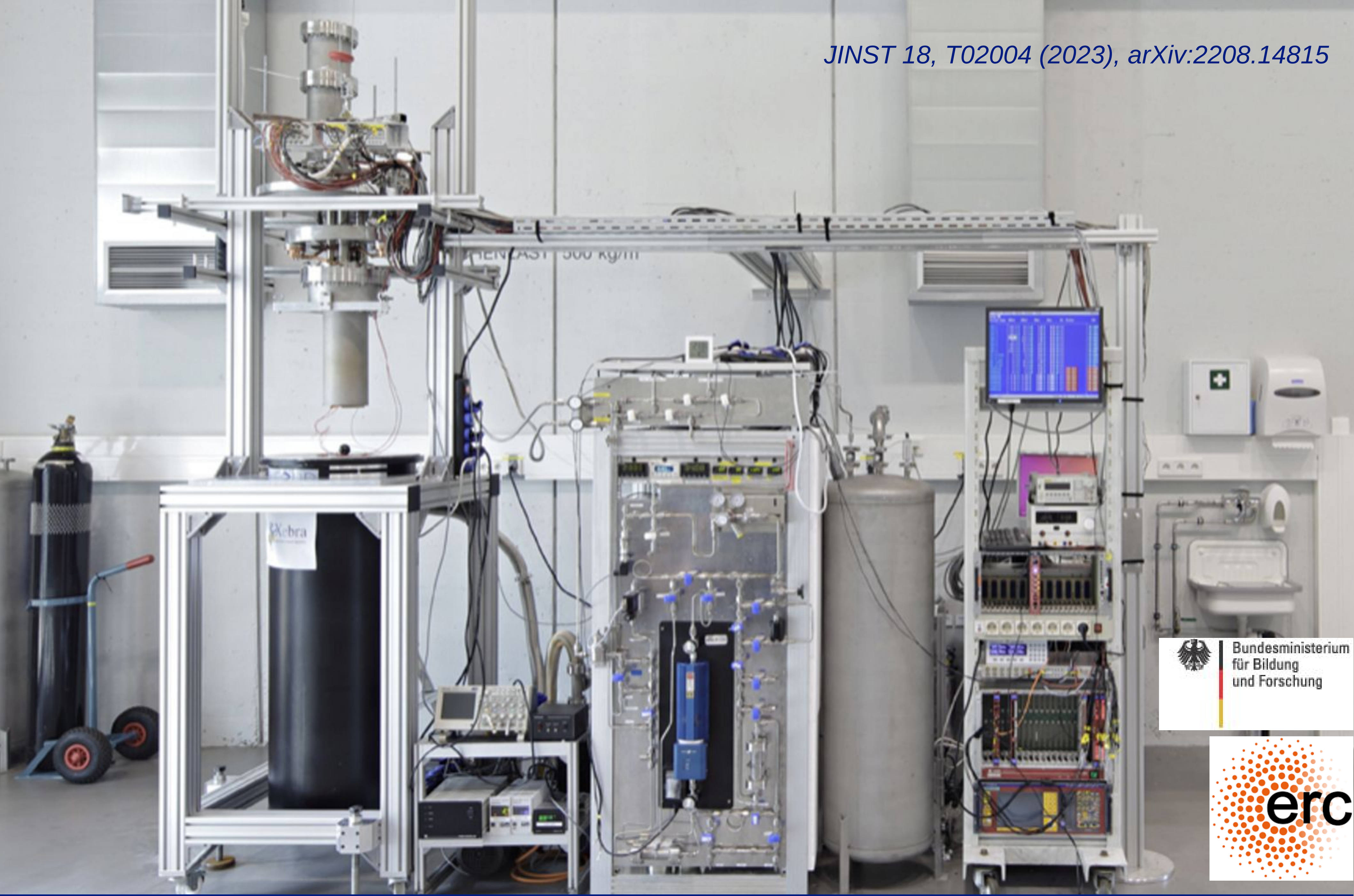
  linear expansion coefficients)
- Electric field homogeneity confirmed with COMSOL
- LXe level control with weir
- Valve connecting both volumes for filling and recuperation

- 2 independent gas systems
- Only one coldfinger, connected to inner volume
- TPC operated on Freiburg‘s XeBRA Test Platform





JINST 18, T02004 (2023), arXiv:2208.14815



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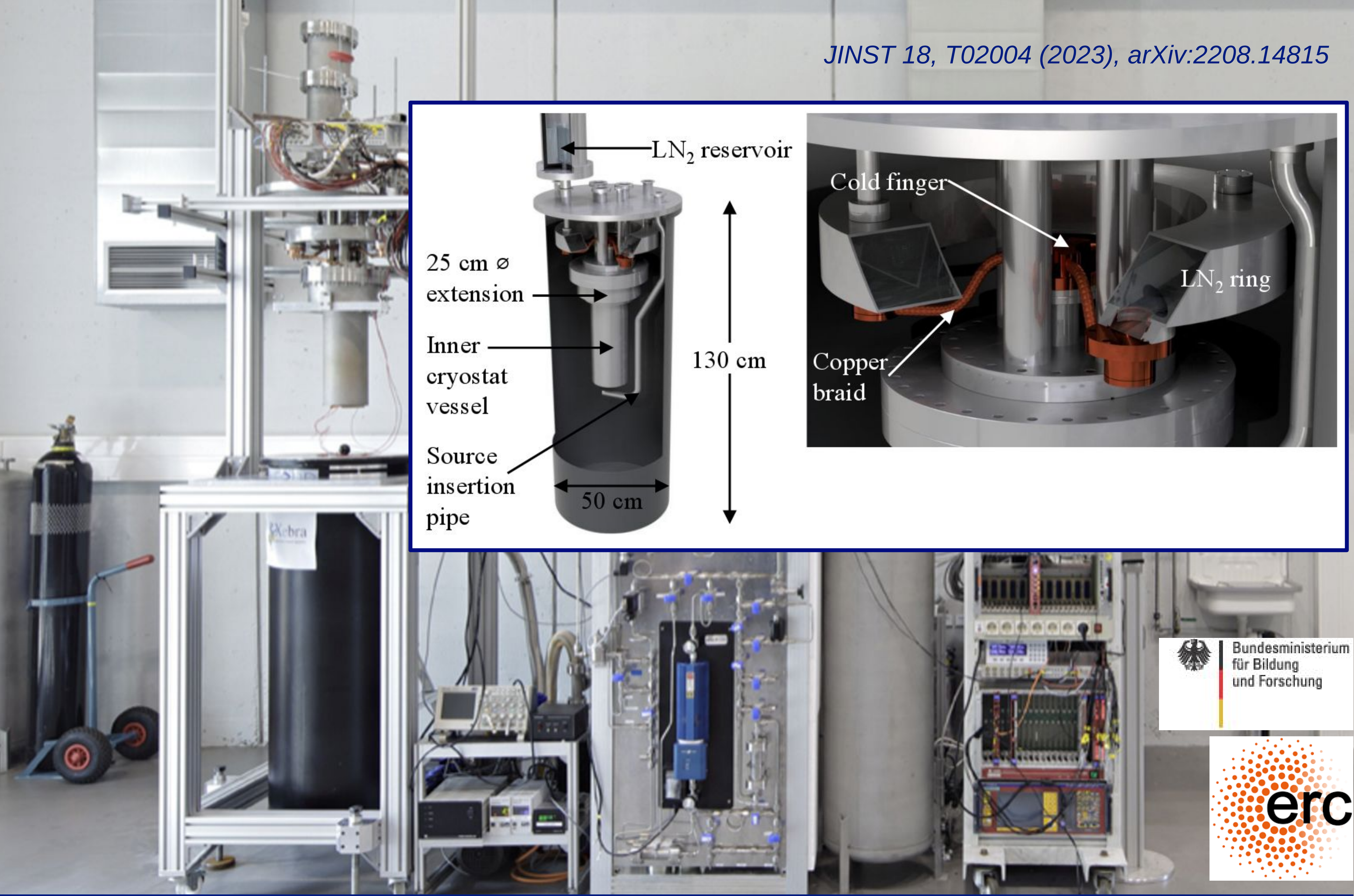
XeBRA Detector Test Platform

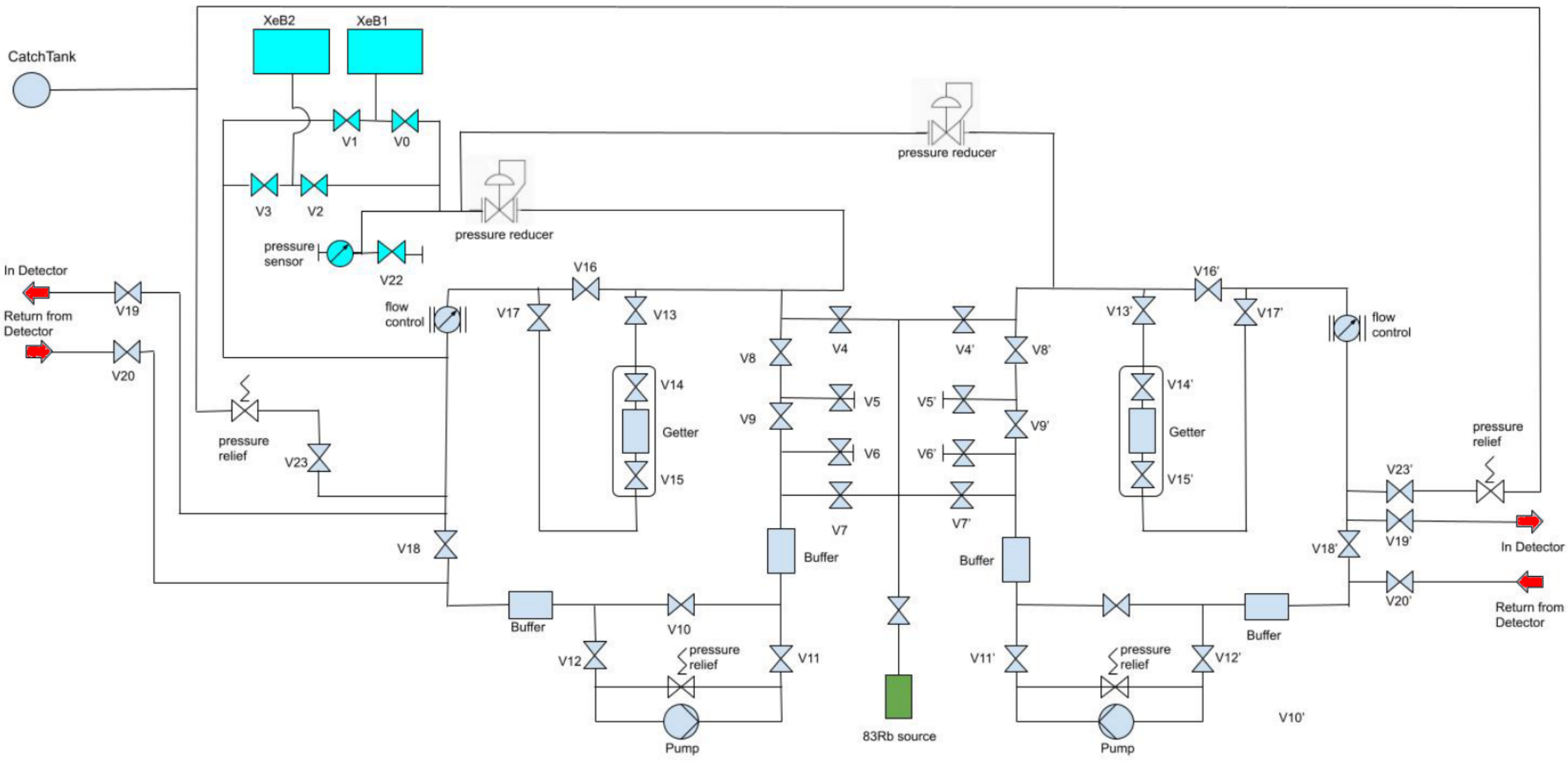
universität freiburg

JINST 18, T02004 (2023), arXiv:2208.14815



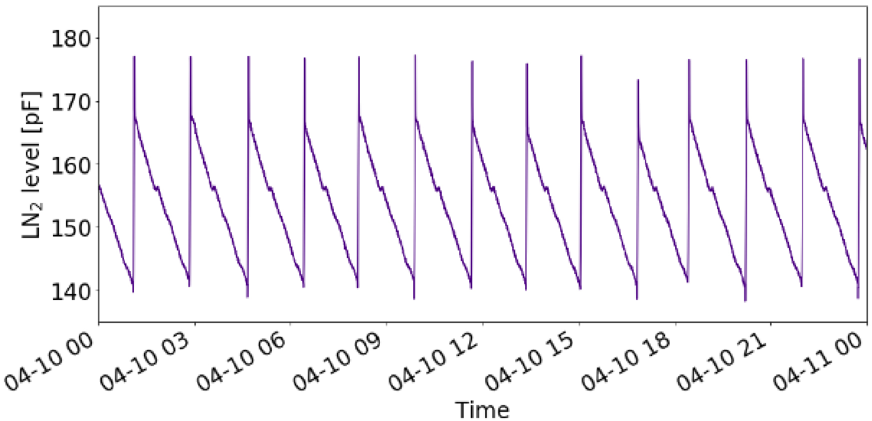
XeBRA Detector Test Platform

Two Gas Systems

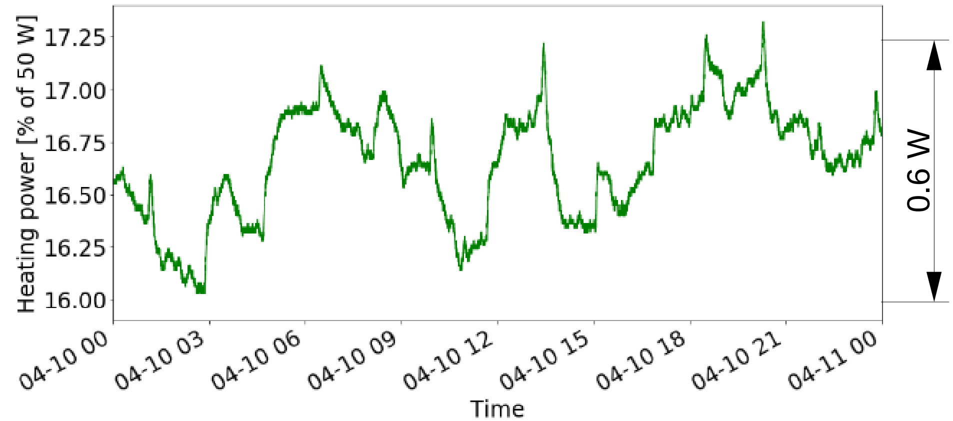


Detector Operation

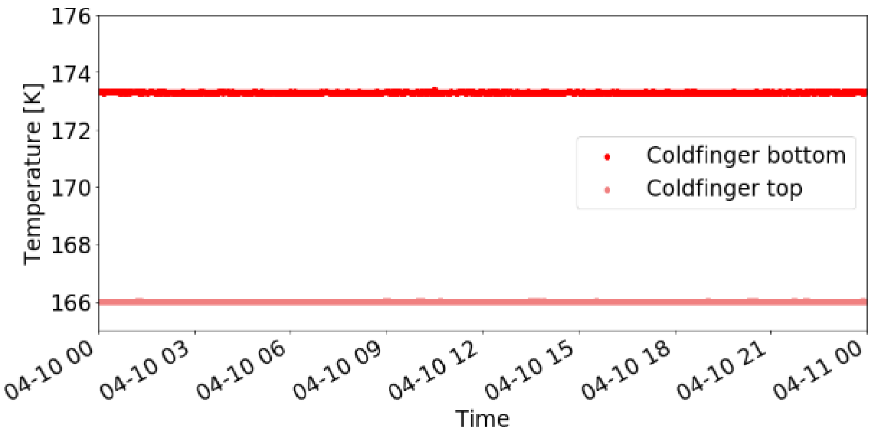
24h examples



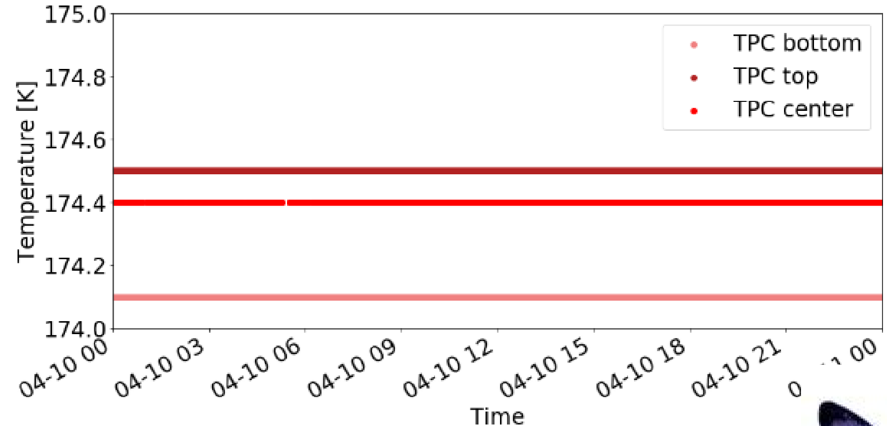
(a) Open flask nitrogen level.



(c) Heating power of the cryogenic controller.



(b) Coldfinger temperatures.



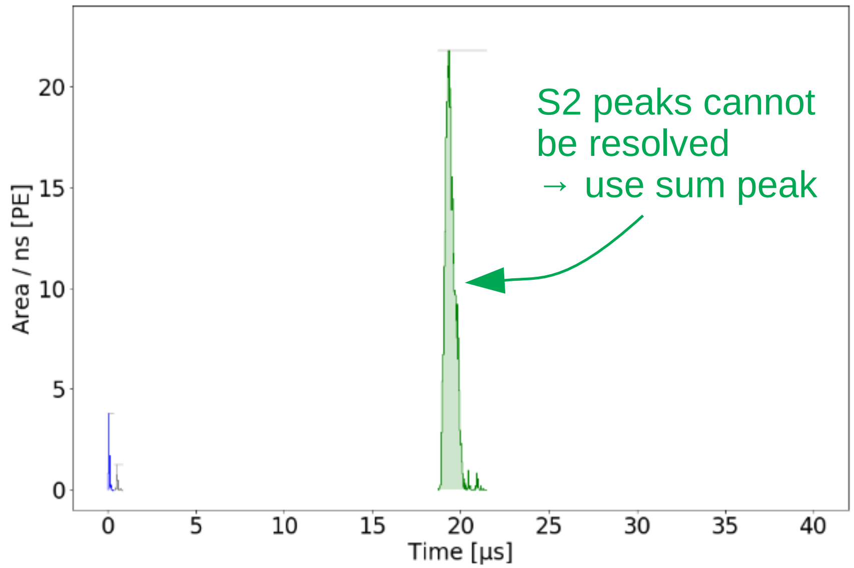
(d) LXe temperatures along TPC.

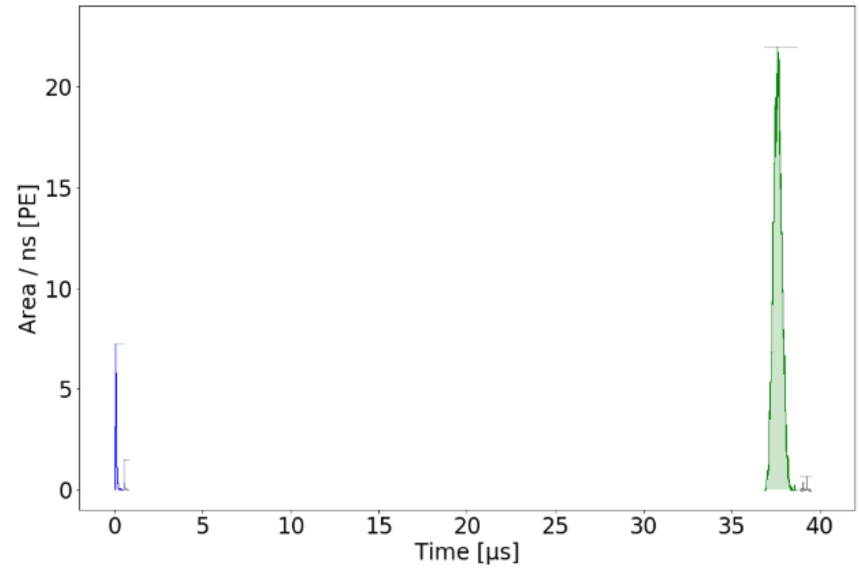
Doberman Slow Control

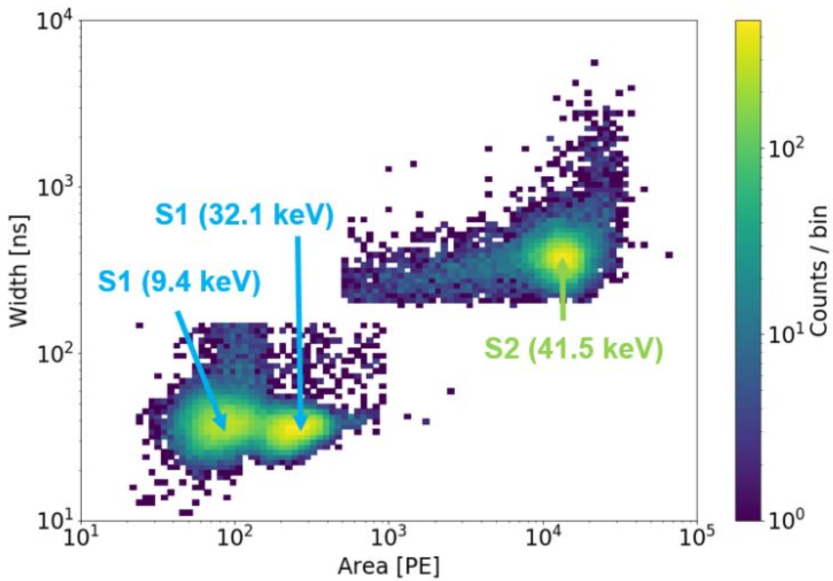
Rely on own Slow Control System Doberman for small/medium applications

JINST 11, T09003 (2016)

TPC Performance







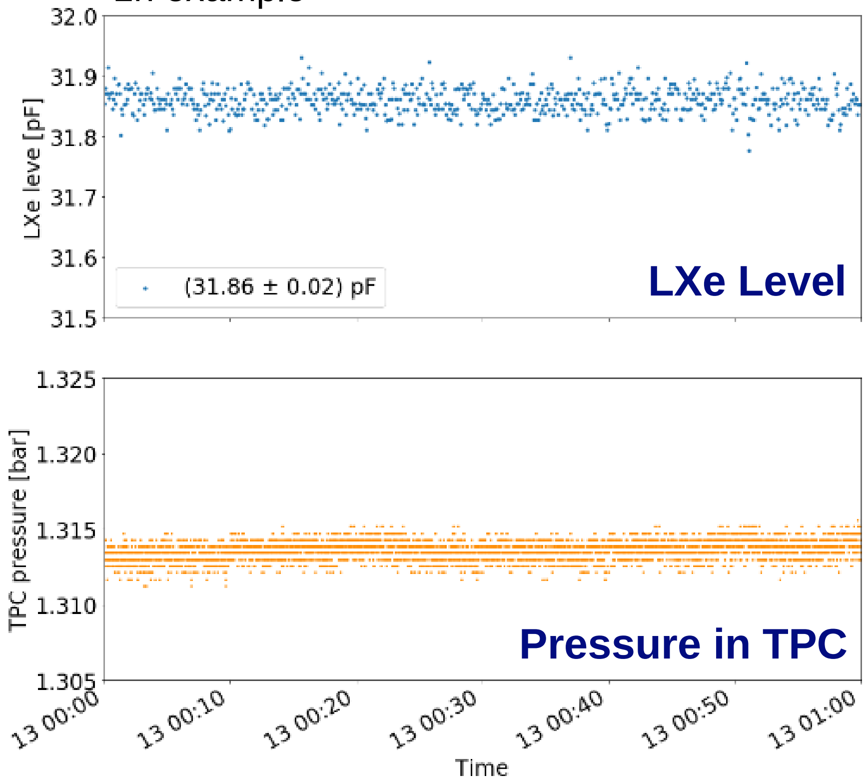
- TPC performance studied with ^{83m}Kr
- **max e⁻-lifetime ~300 µs** (dt_{max}=43 µs)
- correct for *z*-dependence of signals
- decent light and charge-yields:

  g_1=0.089(4) PE/γ

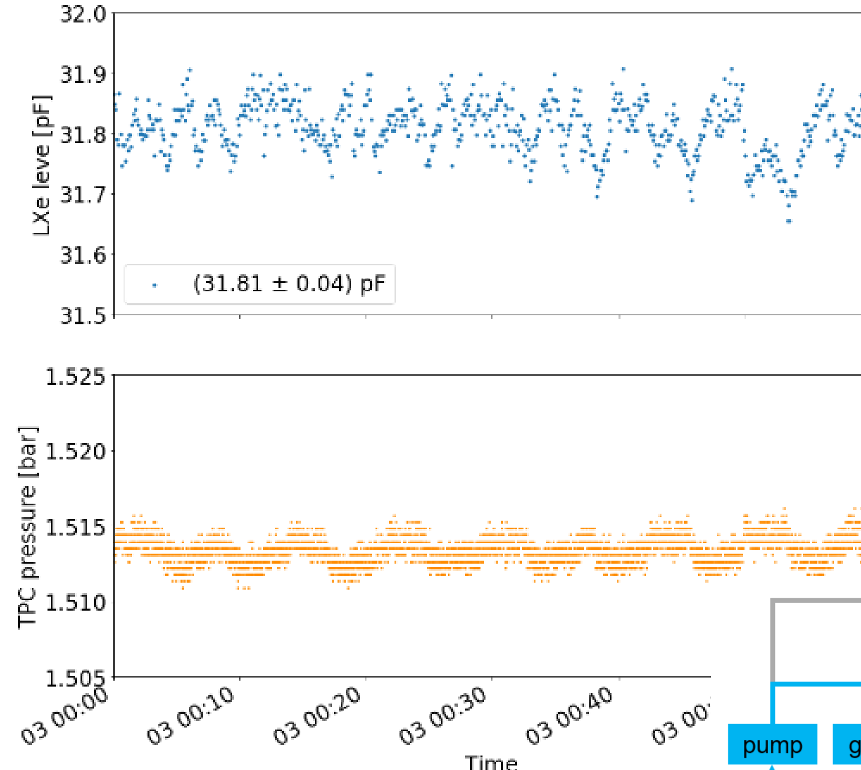
  g_2=7.1(7) PE/e^-
- stable operation only <u>without</u> purifying outer volume (→ level fluctuations)

Fluctuations with two gas systems

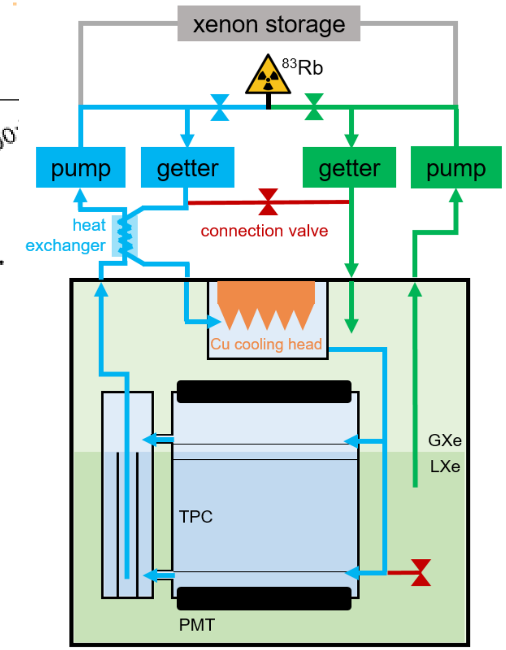
1h example



(a) One gas system online.



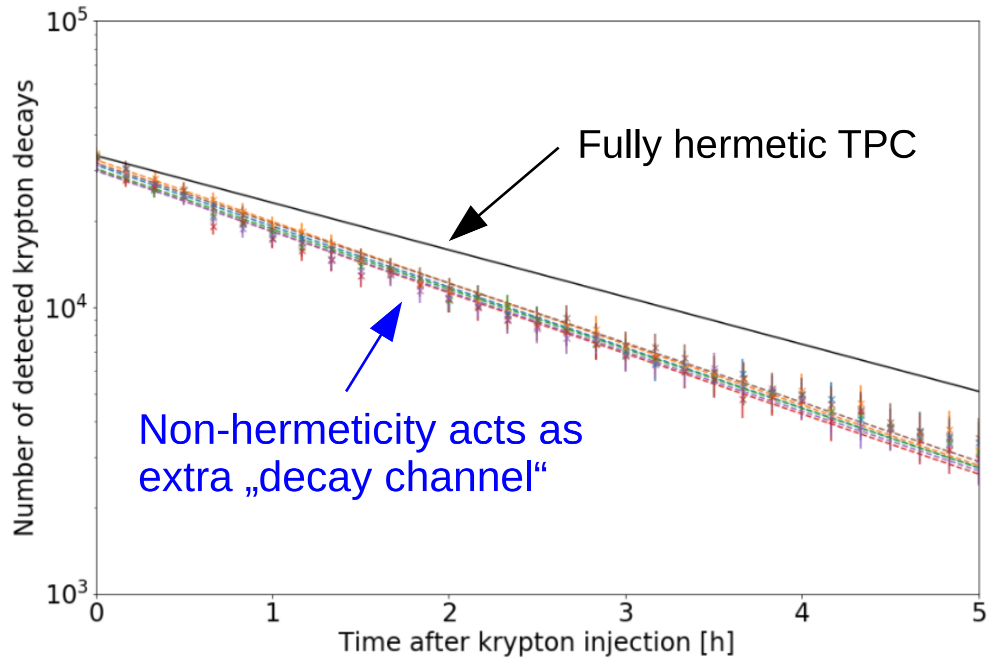
(b) Two gas systems online.

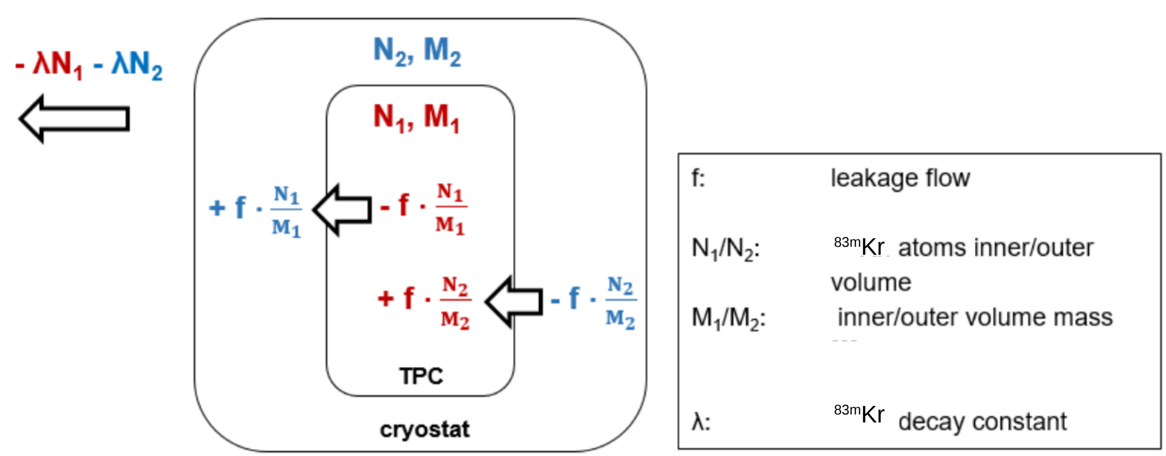


Fluctuations of TPC parameters were probably caused by heat influx into outer volume which could not be compensated due to lack of cold head.

Hermeticity

- Prototype test: leak rate of seals $O(10^{-2})$ mbar l s^{-1} („watertight“)
- Measure Xe leak rate with ^{83m}Kr injected into inner volume via detailed model
- Leakage flow f~0.1 kg/h
  → **semi-hermetic TPC**





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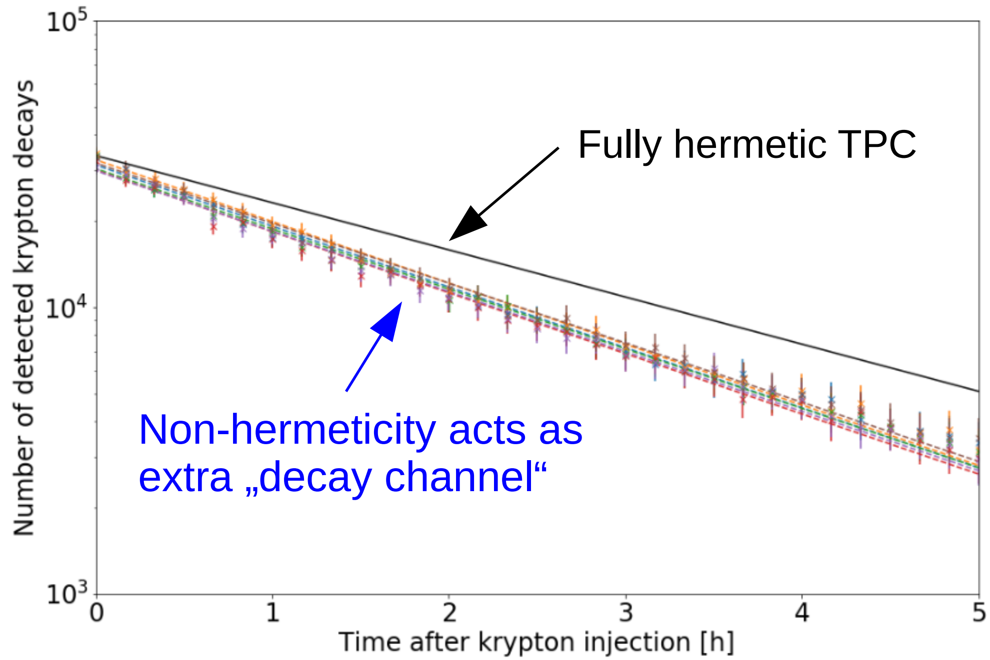
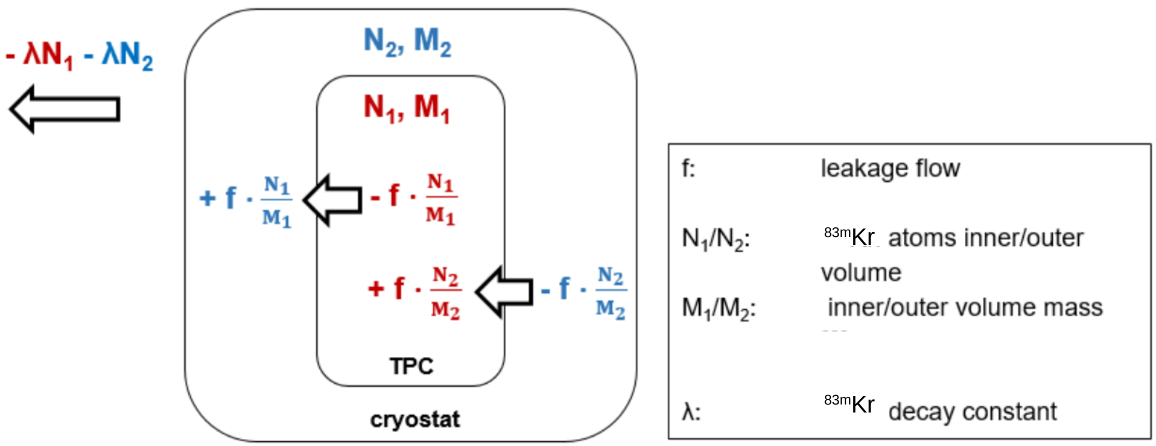
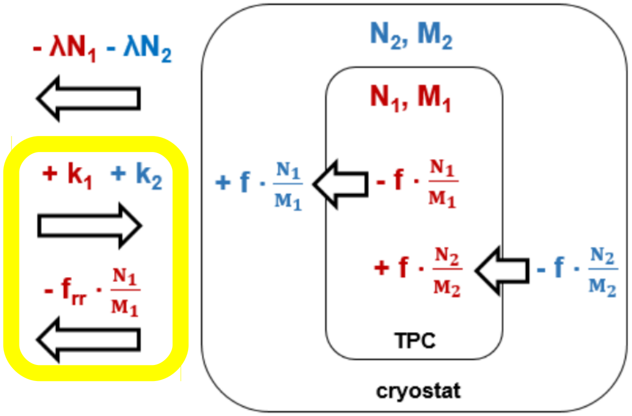


- Origin of leakage unknown. Scale up result to 40t-TPC assuming 3 hypotheses:
  – leak around PMTs
  → r^2 ~1000
  – leak around electrodes
  → r ~ 50
  – leak around tubes/valve
  → ~ 1



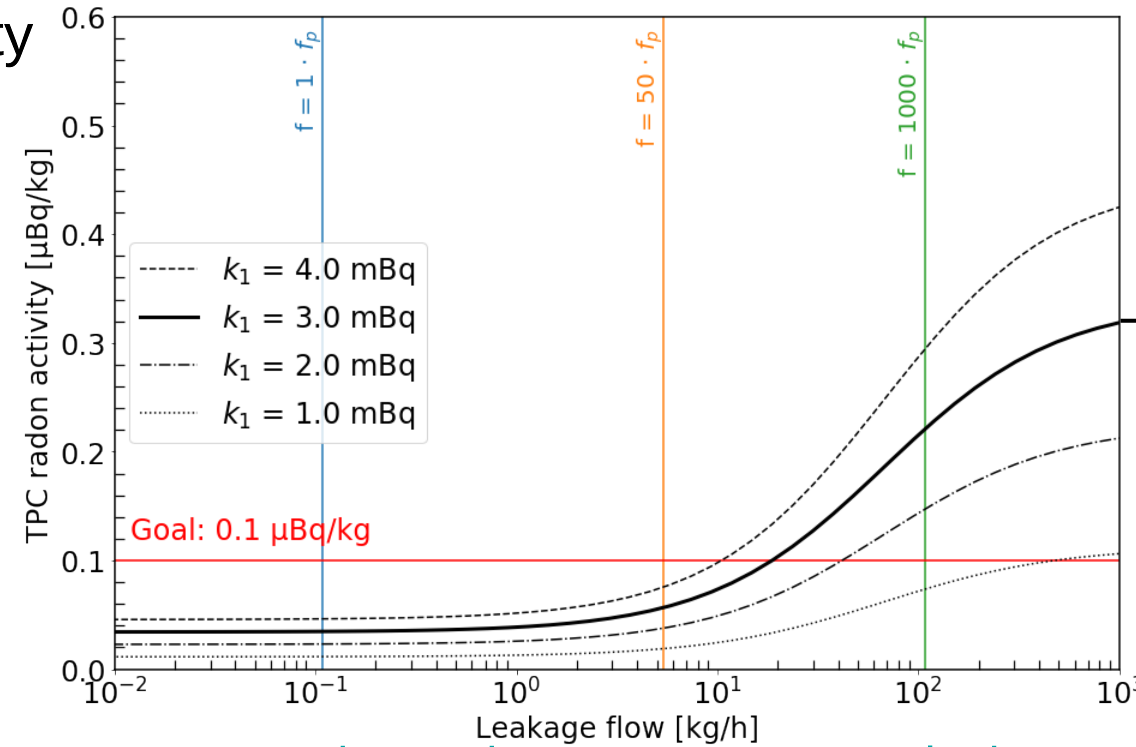
Scaling to G3 Detector: ^{222}Rn

- Expand model to include
  - Rn emanation
    (k_1..inner, k_2..outer volume)
  - Rn removal system
    (flow f_{rr} of Xe through removal system)



f:	leakage flow
f_{rr}:	radon removal flow
N_1/N_2:	^{222}Rn atoms inner/outer volume
M_1/M_2:	inner/outer volume mass
k_1/k_2:	^{222}Rn emanation inner/outer volume
λ:	^{222}Rn decay constant

- Expected Rn-activity in 40t active target:

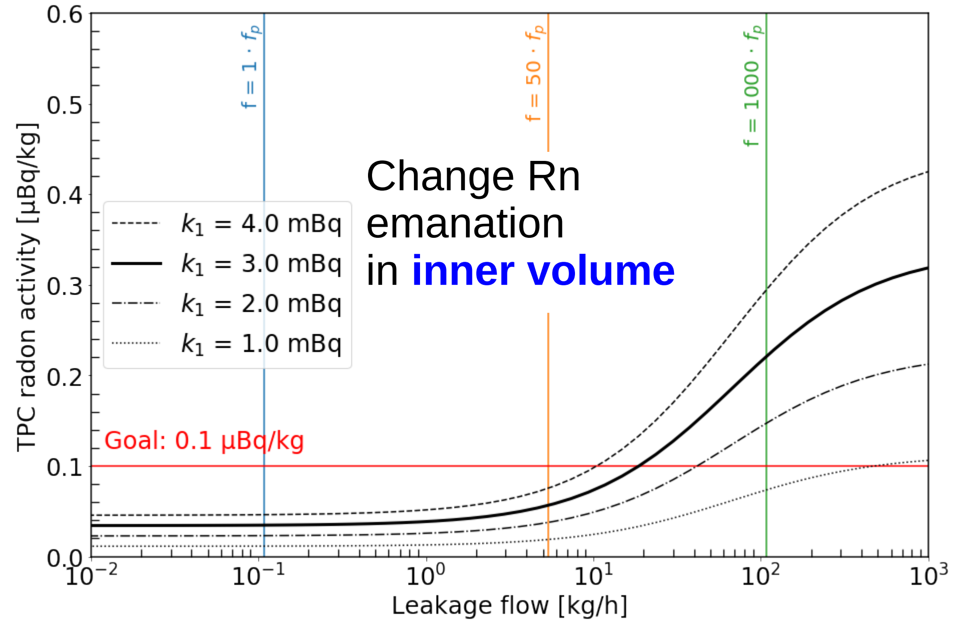


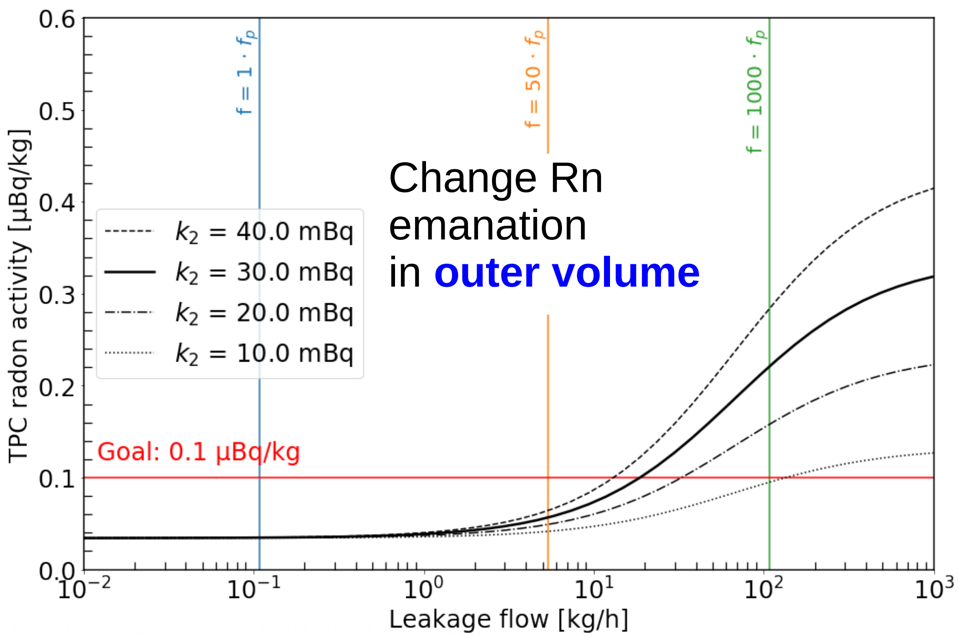
Benchmark numbers:
k_1=3 mBq
k_2=30 mBq
f_{rr}=1000 SLM

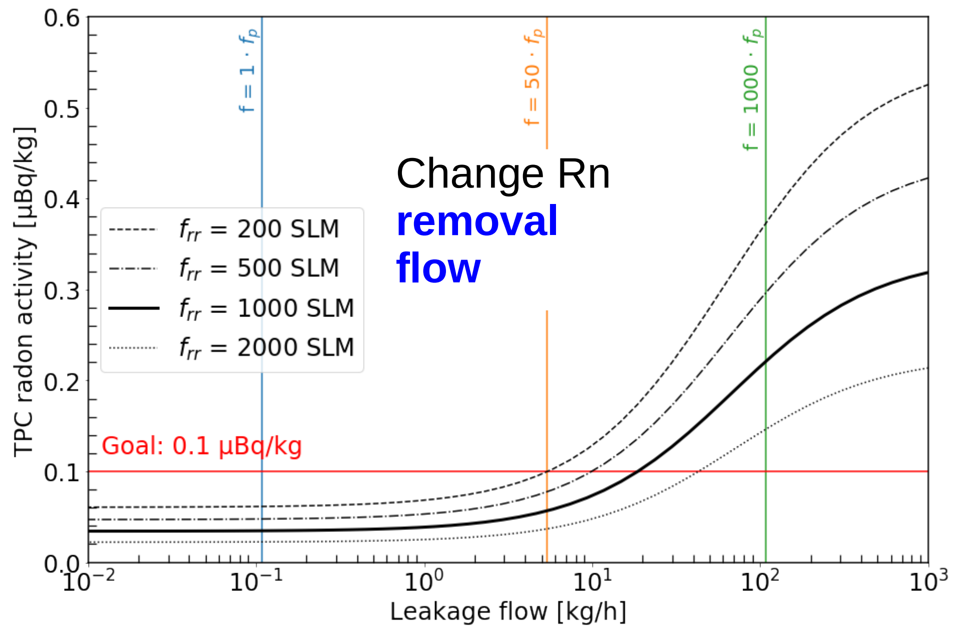
← more hermetic more leaky →

Scaling to G3 Detector: ^{222}Rn

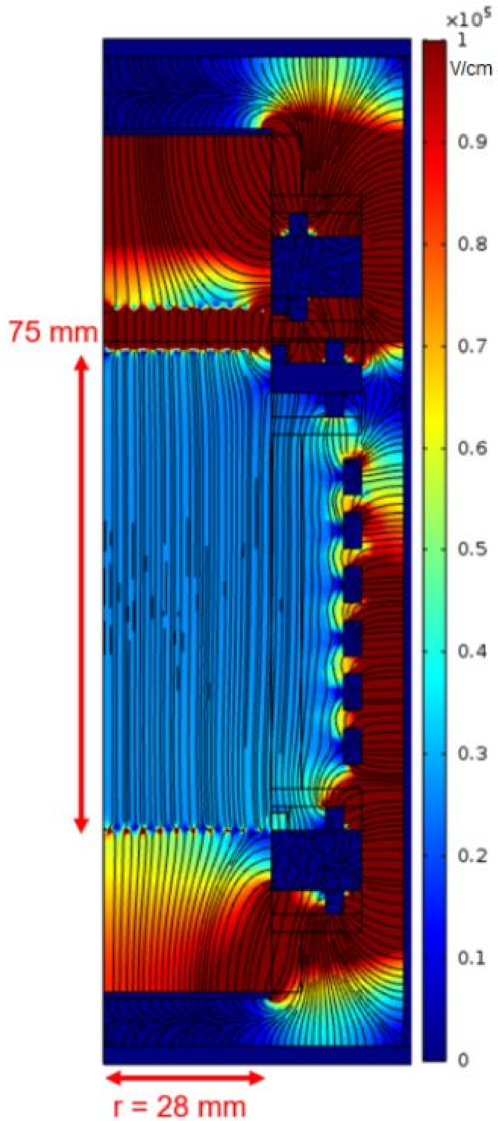
- Study impact of individual Rn parameters
- **Even moderate levels of hermeticity have a significant impact**
- Great potential in combination with other Rn-abatement techniques



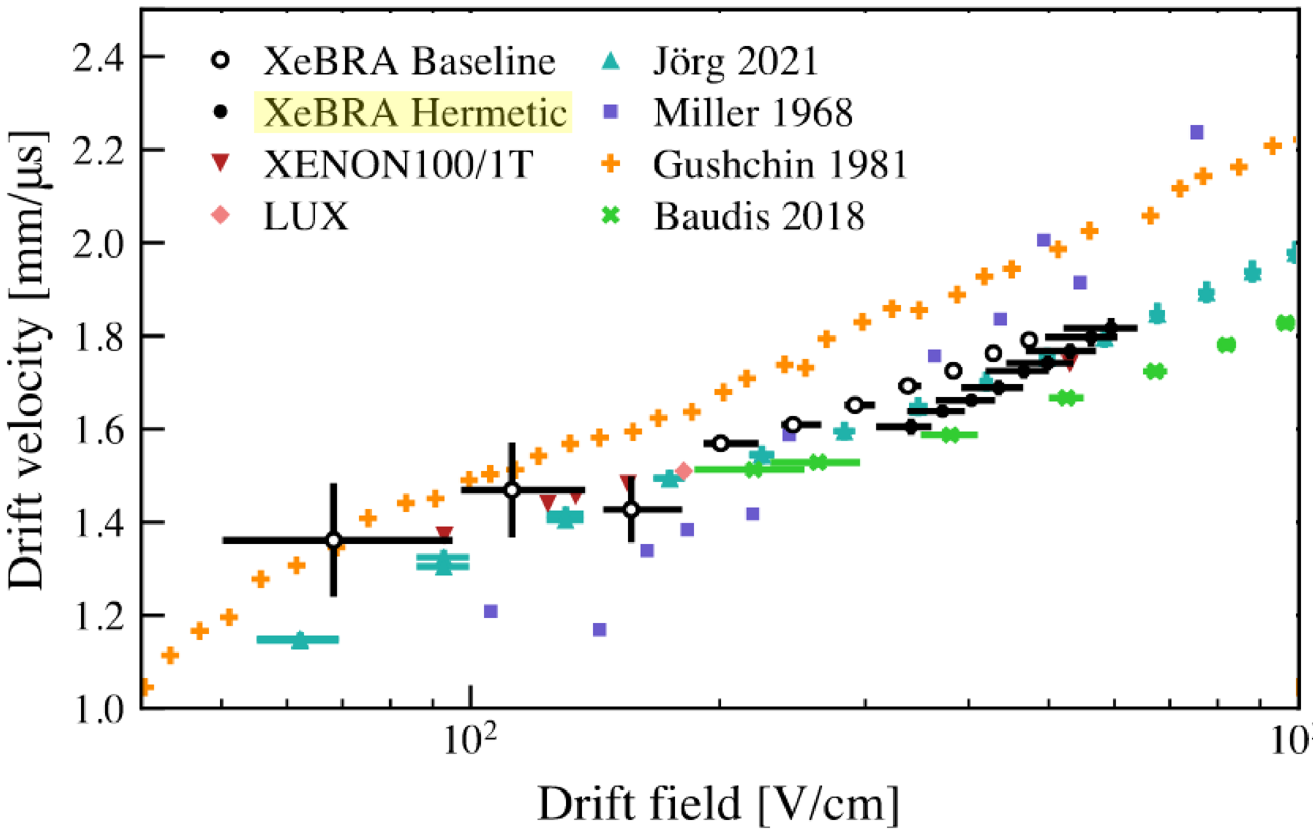




LXe Physics with Hermetic TPC I

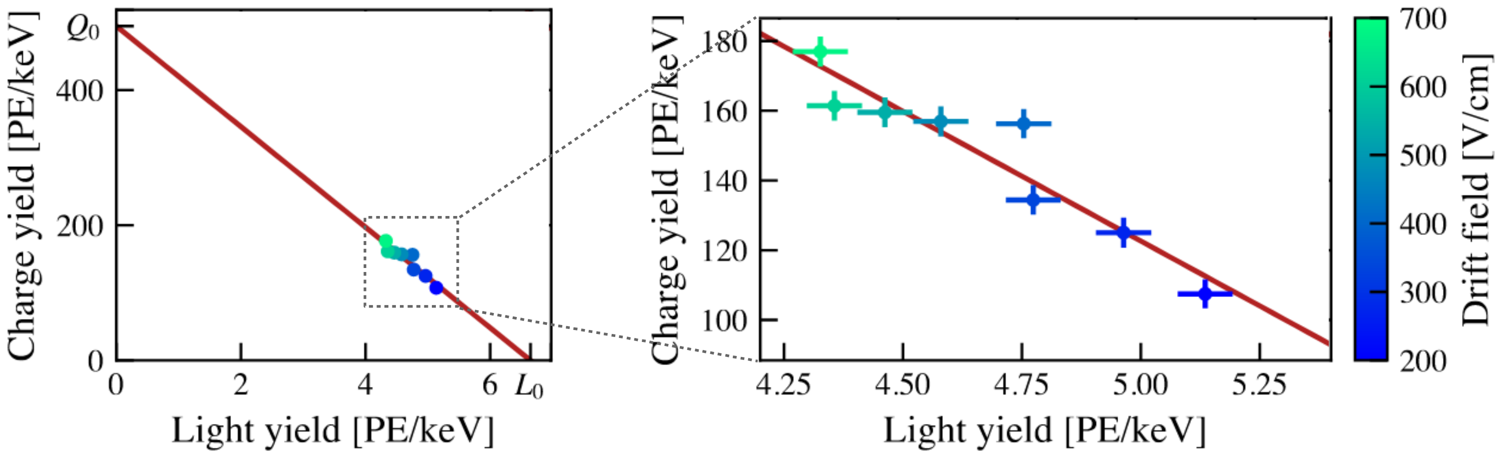


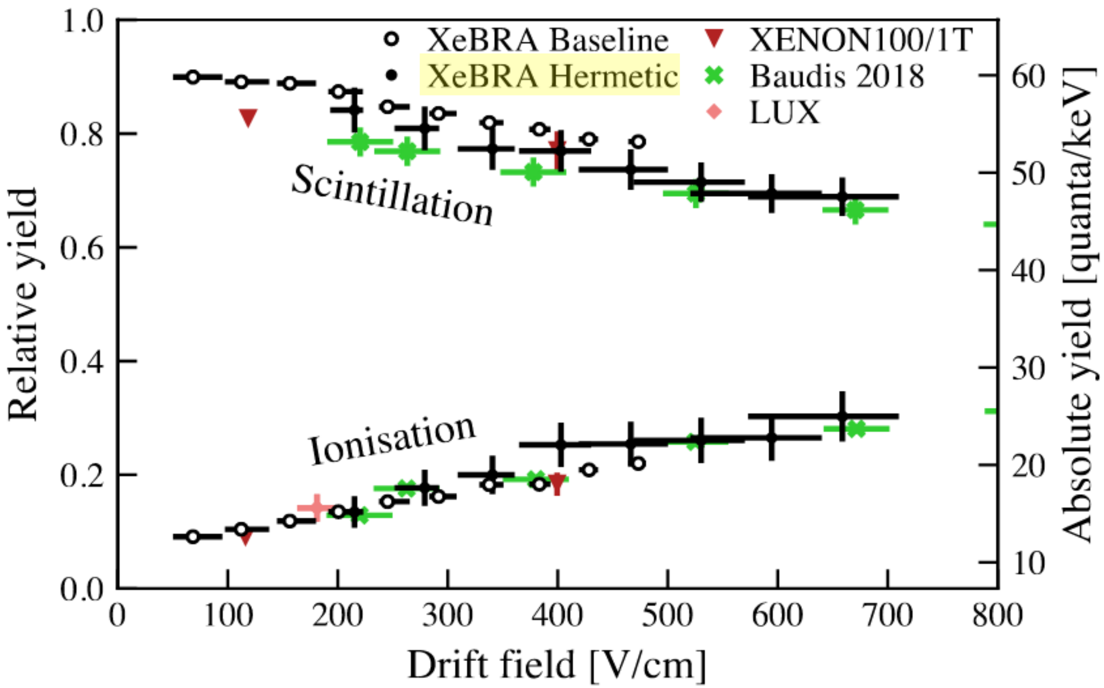
Field dependence of electron drift velocity



LXe Physics with Hermetic TPC II

Field-dependence of light and charge yields





Conclusions

EPJ C 83, 9 (2023)
JINST 18, T02004 (2023)

- We built and operated a small hermetic TPC following the well-established „standard“ TPC design
- Achieved moderate hermeticity using cryofitting
  → method not yet fully optimized
  → more to be studied, also together with Nagoya
- Two independent cooling systems are required to also purify outer volume
- Hermetic TPC operates well
  → measurements of LXe physics

- Already moderate levels of hermeticity can significantly reduce the Rn level
- The hermetic TPC concept is a promising and straightforward approach to reduce Rn in combination with other methods
  → **we should not miss this opportunity**